

**Final report for NRL Grant: N00173-08-1-G014**  
**Tropical Dynamics process studies and numerical methods**

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**Results**

We have developed the skin sea surface temperature (skin SST) model and implemented it in the NOGAPS model. Skin SST is directly responsible for many physical processes in the atmosphere such as, for example, occurrence and strength of the deep atmospheric convection. In turn, these convective systems modulate such large scale weather events in tropics such as tropical cyclone genesis, Madden Julian Oscillations (MJO), flux exchange. To model both skin SST – bulk SST differences as well as their diurnal cycle one dimensional heat transfer equation (Zeng & Beljaars, 2005) was used. Two layers are considered - warm layer and skin layer. The heat budget in these 2 layers defines relationship between skin and bulk temperatures. Solar radiation is distributed in the warm layer and simple exponential decay is assumed. Wind speed is influencing strongly the results – for large wind speeds the differences between skin and bulk SST are small. Cloudiness is taken to account through changes of the solar radiation input. The model is run every prognostic time step of NOGAPS and there is feedback with the convection parameterization in the model. Model input and output are defined in the Table below.

Variable	Description
lh	Latent heat flux ( $\text{W/m}^2$ )
sh	Sensible heat flux ( $\text{W/m}^2$ )
lwo	Net longwave flux ( $\text{W/m}^2$ )
swo	Net shortwave flux ( $\text{W/m}^2$ )
u	Wind speed (m/s)
us	Atmospheric friction velocity
tb	Bulk temperature (deg C)
dtwo	Warm layer temperature difference from previous time (deg C)

Results show the difference of the NOGAPS runs with and without the predictive skin SST and the skin SST anomaly averaged over June 1-15, 2007. One can see large differences in the regions of the Indonesian Maritime Continent and, say, the Arabian Sea. These regions are known to be of crucial importance for propagation of tropical oscillations. Large effects are observed in regions of weak winds and large insolation.

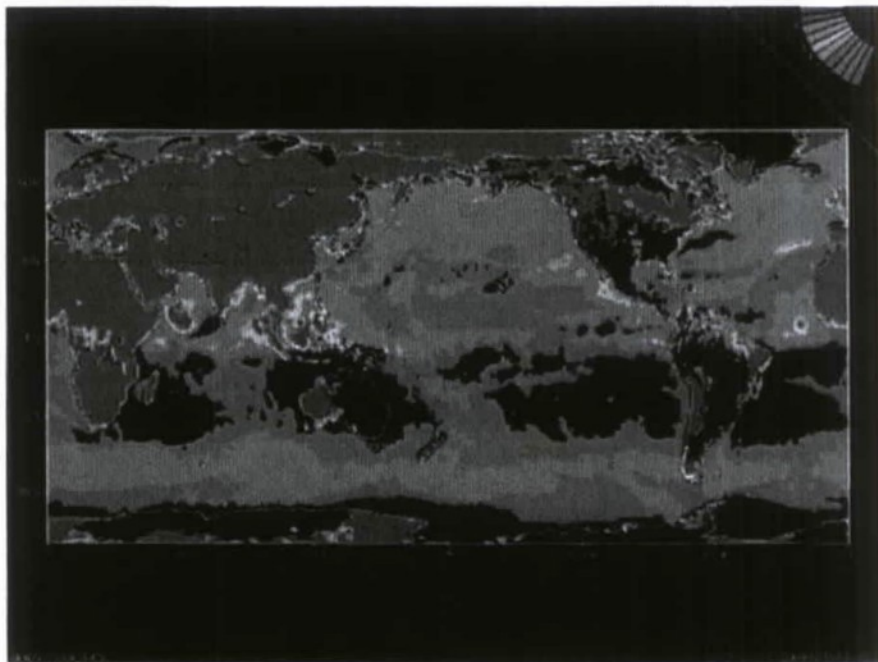
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*Figure. Diurnal skin SST vs constant SST runs of the NOGAPS for June 1-15, 2007. Large effects in tropics are observed for regions of weak winds and large insolation.*

The "skin-SST" scheme was implemented in NOGAPS and used to study dynamical response of the model (projects 6.1MJO, 6.2 Arctic, 6.1 Tyranny of Scales). Ensemble simulations composed of 31 members were conducted for the summer (June, July, and August) of 2007. Effects of the diurnal SST change on the ensemble spread and error and on the behavior of equatorial waves and MJO were examined. In addition influence of tropics on the circulation in the Arctic was studied. The results indicate that skin SST influences dynamical processes in the atmosphere.

The diurnal SST change observed in NOGAPS simulations had largest amplitude in tropical regions, especially in the areas with very weak prevailing winds where the amplitude of the daily SST change could reach 4 °C. The daytime heating influenced equatorially trapped Kelvin waves which are usually difficult to represent in global models. The results of ensemble experiments show that the diurnal skin SST changes helped to maintain the strength of equatorial Kelvin waves, bringing their simulated amplitude closer to observations (Fig. 1). The effects on MJO could also be observed. Higher SSTs in the Indian Ocean, caused by the daytime warming, contribute to stronger MJO convection and larger MJO amplitude. This is particularly visible when MJO is in phase 3-4 with the convection concentrated in the Indian Ocean (Fig. 2).



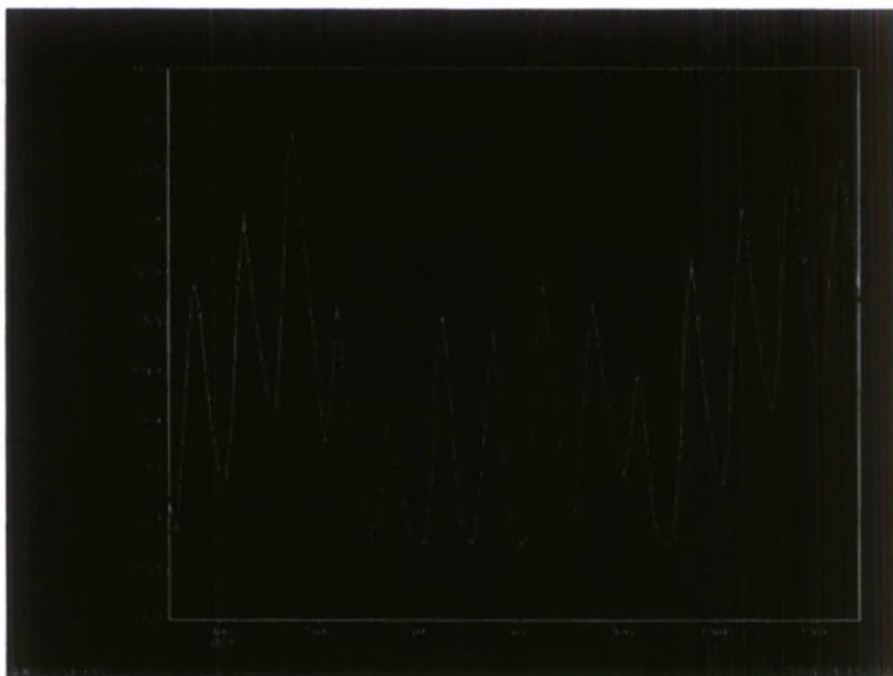


Figure. Skin SST at 2N, 101E for June 1-15, 2007. Diurnal variability of skin SST can reach up to 3-4 degrees C. Such differences influence atmospheric processes in the atmospheric boundary layer.

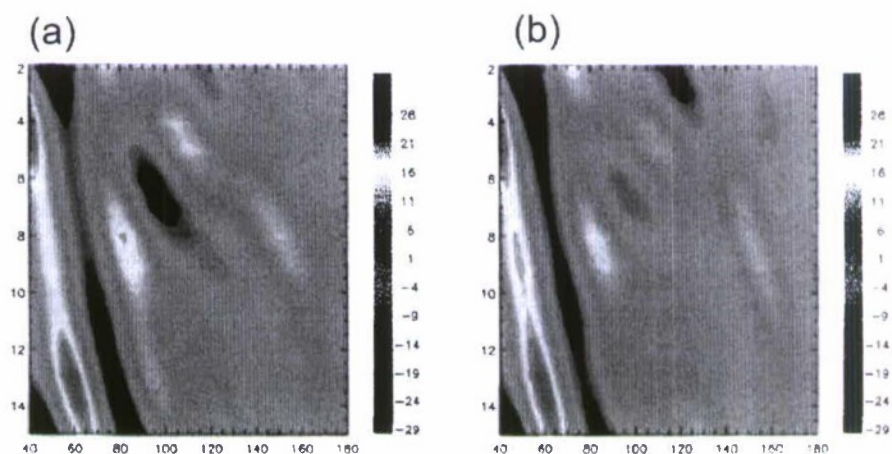


Fig 1. Filtered OLR anomaly during the passage of the Kelvin wave (May of 2007 with values between 26 and -29 W/m<sup>2</sup>. NOGAPS ensemble simulation (ensemble average) with (a) constant SST, (b) diurnal SST variability included. Longitude is plotted between 40 and 180 degrees between May 2 and May 15 of 2007. Increased magnitude of the wave around May 10 is contributed to the diurnal heating in maritime continent.

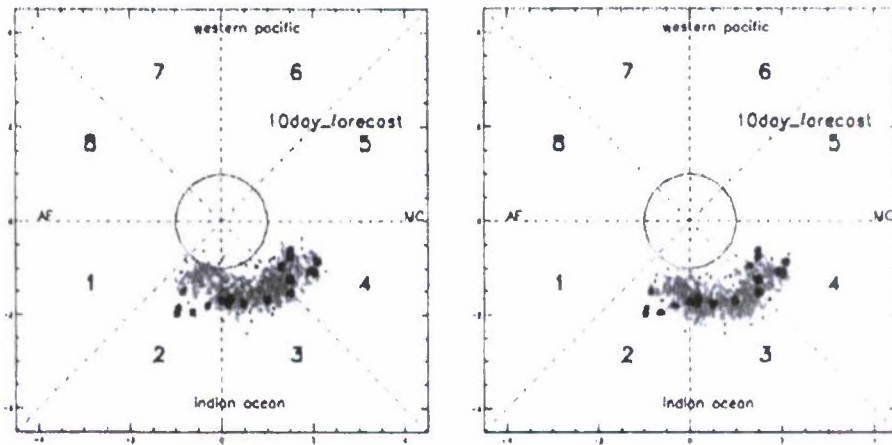


Fig. 2. RMM (Wheeler & Hendon, 2004) diagrams of MJO in June 2007; (a) control run and (b) with the skin SST effect included. The red dots show the MJO state obtained from the 10 day ensemble forecast while the black dots show the verifying analysis. For the control run the amplitude of the modeled MJO is weaker than analysis, while for the skin SST experiments the amplitude increase – especially in phase 3 and 4.

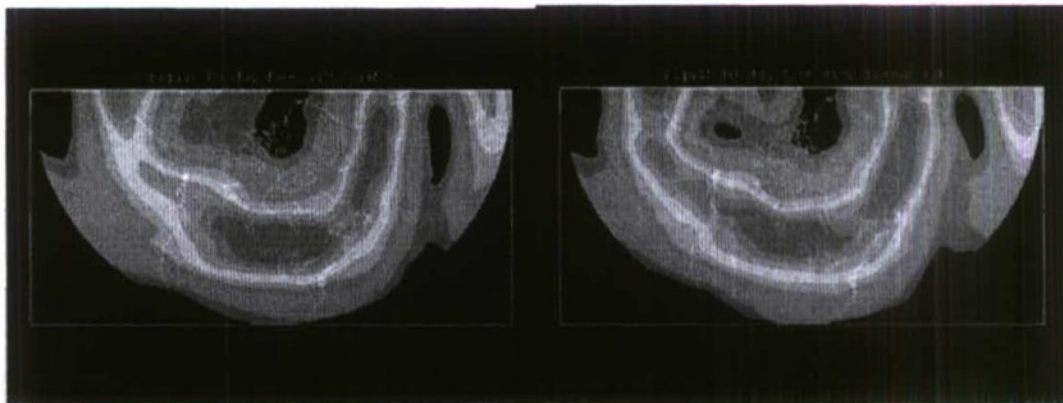


Fig. 3: Influence of the diurnal SST change on Arctic Circulation. The 30 day average for August 200 for the 10 day forecasts of 200 mb zonal winds is shown for (a) control experiment, (b) with the diurnal SST change included. The diurnal SST experiment shows strengthened polar jet over the oceans.

Modification of tropical SST, when diurnal variability was included, impacted the circulation outside the tropics. For example, in the experiments with the diurnal “skin SST” parameterization on, the polar jet was stronger in comparison to the control experiments (Fig. 3).

This result is consistent with the observational evidence of the MJO influence on Arctic Oscillation (L'Heureux & Higgins, 2008). According to observations, MJO convection in phases 2-4 leads to more positive Arctic Oscillation index. As shown in Fig. 2 the MJO convection in this phase increased in the "skin SST" experiment.